BA

Analogs of parathyroid hormone

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Inventor: DONG ZHENG XIN (US)
Applicant: BIOMEASURE INC (US)
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US5723577 (A1)
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Abstract of correspondent: **US5723577**
Peptide variants of fragment (1-34) of parathyroid hormone, in which at least one of the amino acid residues at positions 7, 11, 23, 24, 27, 28, and 31 is cyclohexylalanine, or at least one of the amino acid residues at positions 3, 16, 17, 18, 19, and 34 is alpha -aminoisobutyric acid; or, alternatively, at least the amino acid residue at position 1 is alpha , beta -diaminopropionic acid, the amino acid residue at position 27 is homoarginine, or the amino acid residue at position 31 is norleucine.

Family list
54 family members for:
AU707094
Derived from 44 applications.

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1 **ANALOGA DES PARATHYROID-HORMONS**
Publication info: **AT250425T T** - 2003-10-15

2 **Analogs of parathyroid hormone**
Publication info: **AU707094 B2** - 1999-07-01

3 **Analogs of parathyroid hormone**
Publication info: **AU741584 B2** - 2001-12-06

4 **Analogs of parathyroid hormone**
Publication info: **AU5519998 A** - 1998-08-03

5 **Analogs of parathyroid hormone**
Publication info: **AU6483496 A** - 1997-02-10

6 **ANALOGS OF PARATHYROID HORMONE**
Publication info: **BR9714200 A** - 2000-03-28

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Publication info: **CA2226177 A1** - 1997-01-30

8 **ANALOGS OF PARATHYROID HORMONE**
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Publication info: **CN1137898C C** - 2004-02-11
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Publication info: **CN1199340 A** - 1998-11-18

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12 **Analogs of parathyroid hormone**
Publication info: **DE69630133T T2** - 2004-06-09

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Publication info: **DK847278T T3** - 2003-12-22

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EP0847278 A4 - 1999-01-13
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19 **ANALOGS OF PARATHYROID HORMONE**
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IL122837D D0 - 1998-08-16

22 No English title available
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Publication info: **JP11509201T T** - 1999-08-17

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Family list
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Publication info: **WO9702834 A1** - 1997-01-30

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US005723577A

United States Patent [19]

Dong

[11] Patent Number: 5,723,577

[45] Date of Patent: Mar. 3, 1998

[54] **ANALOGS OF PARATHYROID HORMONE**

[75] Inventor: **Zheng Xin Dong**, Framingham, Mass.

[73] Assignee: **Biomeasure Inc.**, Milford, Mass.

[21] Appl. No.: **626,186**

[22] Filed: **Mar. 29, 1996**

Related U.S. Application Data

[60] Provisional application Nos. 60/001,105, Jul. 13, 1995 and 60/003,305, Sep. 6, 1995.

[51] **Int. Cl.**[6] **A61K 38/29**; C07K 14/635

[52] **U.S. Cl.** **530/324**; 514/12

[58] **Field of Search** 436/86; 530/324, 530/399; 514/12

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Primary Examiner—Jeffrey E. Russel

Attorney, Agent, or Firm—Fish & Richardson P. C.

[57] **ABSTRACT**

Peptide variants of fragment (1–34) of parathyroid hormone, in which at least one of the amino acid residues at positions 7, 11, 23, 24, 27, 28, and 31 is cyclohexylalanine, or at least one of the amino acid residues at positions 3, 16, 17, 18, 19, and 34 is α-aminoisobutyric acid; or, alternatively, at least the amino acid residue at position 1 is α,β-diaminopropionic acid, the amino acid residue at position 27 is homoarginine, or the amino acid residue at position 31 is norleucine.

23 Claims, No Drawings

ANALOGS OF PARATHYROID HORMONE

CROSS REFERENCE TO RELATED APPLICATIONS

Under 35 USC §119(e), this application claims the benefit of prior U.S. provisional application 60/001.105 filed Jul. 13, 1995 and prior U.S. provisional application 60/003.305, filed Sep. 6, 1995.

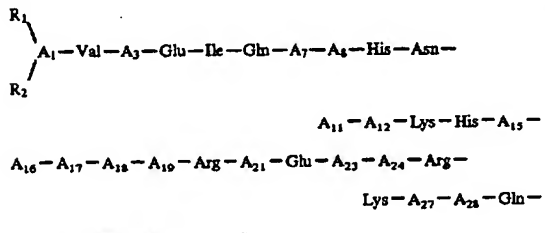
BACKGROUND OF THE INVENTION

Parathyroid hormone ("PTH") is a polypeptide produced by the parathyroid glands. The mature circulating form of the hormone is comprised of 84 amino acid residues. The biological action of PTH can be reproduced by a peptide fragment of its N-terminus (e.g. amino acid residues 1 through 34). Parathyroid hormone-related protein ("PTHrP") is a 139 to 173 amino acid-protein with N-terminal homology to PTH. PTHrP shares many of the biological effects of PTH including binding to a common PTH/PTHrP receptor. Tregear, et al., Endocrinol., 93:1349 (1983). PTH peptides from many different sources, e.g., human, bovine, rat, chicken, have been characterized. Nissenson, et al., Receptor, 3:193 (1993).

PTH has been shown to both improve bone mass and quality. Dempster, et al., Endocrine Rev., 14:690 (1993); and Riggs, Amer. J. Med., 91 (Suppl. 5B):37S (1991). The anabolic effect of intermittently administered PTH has been observed in osteoporotic men and women either with or without concurrent antiresorptive therapy. Slovik, et al., J. Bone Miner. Res., 1:377 (1986); Reeve, et al., Br. Med. J., 301:314 (1990); and Hesch, R-D., et al., Calcif. Tissue Int'l, 44:176 (1989).

SUMMARY OF THE INVENTION

In one aspect, the invention relates to peptide variants of PTH(1–34) of the following generic formula:



wherein

A_1 is Ser, Ala, or Dap;

A_3 is Ser, Thr, or Aib;

A_7 is Leu, Nle, Cha, β-Nal, Trp, Pal, Phe, or p-X-Phe in which X is OH, a halogen, or CH_3;

A_8 is Met, Nva, Leu, Val, Ile, or Nle;

A_{11} is Leu, Nle, Cha, β-Nal, Trp, or Phe;

A_{12} is Gly or Aib;

A_{15} is Leu or Cha;

A_{16} is Ser, Asn, Ala, or Aib;

A_{17} is Ser, Thr, or Aib;

A_{18} is Met, Nva, Leu, Val, Ile, Nle, or Aib;

A_{19} is Glu or Aib;

A_{21} is Val or Met;

A_{23} is Trp or Cha;

A_{24} is Leu or Cha;

A_{27} is Lys, Aib, Leu, hArg, Gln, or Cha;

A_{28} is Leu or Cha;

A_{30} is Asp or Lys;

A_{31} is Val, Nle, or Cha;

A_{32} is His or deleted;

A_{33} is Asn or deleted;

A_{34} is Phe, Tyr, Amp, Aib, or deleted;

each of R_1 and R_2 is, independently, H, C_{1-12} alkyl, C_{2-12} alkenyl, C_{7-20} phenylalkyl, C_{11-20} naphthylalkyl, C_{1-12} hydroxyalkyl, C_{2-12} hydroxyalkenyl, C_{7-20} hydroxyphenylalkyl, or C_{11-20} hydroxynaphthylalkyl; or one and only one of R_1 and R_2 is COE_1 in which E_1 is C_{1-12} alkyl, C_{2-12} alkenyl, C_{7-20} phenylalkyl, C_{11-20} naphthylalkyl, C_{1-12} hydroxyalkyl, C_{2-12} hydroxyalkenyl, C_{7-20} hydroxy-phenylalkyl, or C_{11-20} hydroxynaphthylalkyl;

R_3 is OH, NH_2, C_{1-12} alkoxy, or NH—Y—CH_2—Z where Y is a C_{1-12} hydrocarbon moiety and Z is H, OH, CO_2H, or $CONH_2$;

provided that (i) at least one of A_7, A_{11}, A_{15}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha, or at least one of A_3, A_{16}, A_{17}, A_{18}, A_{19}, and A_{34} is Aib, or that (ii) at least A_1 is Dap, A_{27} is hArg, or A_{31} is Nle; or a pharmaceutically acceptable salt thereof.

A subset of the compounds covered by the above formula are those in which at least one of A_7, A_{11}, A_{15}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha. For example, A_3 is Ser; A_5 is Ile; A_7 is Leu or Cha; A_8 is Met, Nva, Leu, Val, Ile, or Nle; A_{11} is Leu or Cha; A_{12} is Gly; A_{16} is Asn or Aib; A_{17} is Ser; A_{18} is Met or Nle; A_{21} is Val; A_{27} is Lys, hArg, or Cha; A_{32} is His; A_{31} is Val, Nle, or Cha; A_{33} is Asn; A_{34} is Phe, Tyr, Amp, or Aib; R_1 is H; R_2 is H; and R_3 is NH_2; provided that at least one of A_5, A_7, A_8, A_{11}, A_{15}, A_{18}, A_{21}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha, or at least one of A_3, A_{12}, A_{16}, A_{17}, A_{18}, A_{19}, and A_{34} is Aib. If desired, at least one of A_7 and A_{11} can be Cha; or at least one of A_{15}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha.

In another subset, at least one of A_3, A_{12}, A_{16}, A_{17}, A_{18}, A_{19}, and A_{34} is Aib. For example, A_3 is Ser or Aib; A_5 is Ile; A_7 is Leu or Cha; A_8 is Met, Nva, Leu, Val, Ile, or Nle; A_{11} is Leu or Cha; A_{16} is Asn or Aib; A_{18} is Met, Aib, or Nle; A_{21} is Val; A_{27} is Lys, Aib, Leu, hArg, or Cha; A_{31} is Val, Nle, or Cha; A_{32} is His; A_{33} is Asn; A_{34} is Phe, Tyr, Amp, or Aib; R_1 is H; R_2 is H; and R_3 is NH_2; provided that at least one of A_5, A_7, A_8, A_{11}, A_{15}, A_{18}, A_{21}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha, or at least one of A_3, A_{12}, A_{16}, A_{17}, A_{18}, A_{19}, and A_{34} is Aib. If desired, at least one of A_7 and A_{11} can be Cha; or at least one of A_{15}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha.

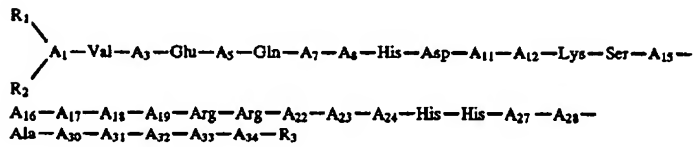
In a still further subset, at least one of A_7, A_{11}, A_{15}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha and at least one of A_3, A_{12}, A_{16}, A_{17}, A_{18}, A_{19}, and A_{34} is Aib; provided that at least one of A_5, A_7, A_8, A_{11}, A_{15}, A_{18}, A_{21}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha, or at least one of A_3, A_{12}, A_{16}, A_{17}, A_{18}, A_{19}, and A_{34} is Aib. For example, A_3 is Ser or Aib; A_5 is Ile; A_7 is Leu or Cha; A_8 is Met, Nva, Leu, Val, Ile, or Nle; A_{11} is Leu or Cha; A_{16} is Asn or Aib; A_{18} is Met, Aib, or Nle; A_{21} is Val; A_{27} is Lys, Aib, Leu, hArg, or Cha; A_{31} is Val, Nle, or Cha; A_{32} is His; A_{33} is Asn; A_{34} is Phe, Tye, Amp, or Aib; R_1 is H; R_2 is H; and R_3 is NH_2. If desired, at least one of A_7 and A_{11} is Cha and at least one of A_{16}, A_{19}, and A_{34} is Aib; or at least one of A_{24}, A_{28}, and A_{31} is Cha and at least one of A_{16} and A_{17} is Aib.

In yet another subset, A_1 is Ser, Gly, or Dap; A_3 is Ser or Aib; A_5 is Ile; A_7 is Leu or Cha; A_8 is Met, Nva, Leu, Val, Ile, or Nle; A_{16} is Asn or Aib; A_{18} is Met, Aib, or Nle; A_{21} is Val; A_{27} is Lys, Aib, Leu, hArg, or Cha; A_{31} is Val, Nle, or Cha; A_{32} is His; A_{33} is Asn; A_{34} is Phe, Tyr, Amp, or Aib;

R_1 is H; R_2 is H; and R_3 is NH_2; provided that at least A_1 is Dap, A_{27} is hArg, or A_{31} is Nle.

The following are examples of the peptide of this invention as covered by the above formula: [Nle^{31}]hPTH(1–34)NH_2; [$hArg^{27}$]hPTH(1–34)NH_2; [Dap^1, $Nle^{8,18}$, Tyr^{34}]hPTH(1–34)NH_2; [Nle^{31}]bPTH(1–34)NH_2; [Nle^{31}]rPTH(1–34)NH_2; [$hArg^{27}$]bPTH(1–34)NH_2; [$hArg^{27}$]rPTH(1–34)NH_2; [Cha^7]hPTH(1–34)NH_2; [Cha^{11}]hPTH(1–34)NH_2; [Cha^{15}]hPTH(1–34)NH_2; [$Cha^{7,11}$]hPTH(1–34)NH_2; [Cha^{11}, $Nle^{8,18}$, Tyr^{34}]hPTH(1–34)NH_2; [Cha^{23}]hPTH(1–34)NH_2; [Cha^{24}]hPTH(1–34)NH_2; [$Nle^{8,18}$, Cha^{27}]hPTH(1–34) NH_2; [Cha^{28}]hPTH(1–34) NH_2; [Cha^{31}]hPTH(1–34)NH_2; [Cha^{27}]hPTH(1–34)NH_2; [$Cha^{27,29}$]hPTH(1–34)NH_2; [Cha^{28}]bPTH(1–34)NH_2; [Cha^{28}]rPTH(1–34)NH_2; [$Cha^{24,28,31}$]hPTH(1–34)NH_2; [Aib^{16}]hPTH(1–34)NH_2; [Aib^{19}]hPTH(1–34)NH_2; [Aib^{34}]hPTH(1–34)NH_2; [$Aib^{16,19}$]hPTH(1–34)NH_2; [$Aib^{16,19,34}$]hPTH(1–34)NH_2; [$Aib^{16,34}$]hPTH(1–34)NH_2; [$Aib^{19,34}$]hPTH(1–34)NH_2; [$Cha^{7,11}$ $Nle^{8,18}$, $Aib^{16,19}$ Tyr^{34}]hPTH(1–34)NH_2; [$Cha^{7,11}$, $Nle^{8,18,31}$, $Aib^{16,19}$, Tyr^{34}]hPTH(1–34)NH_2; [Cha^7, Aib^{16}]hPTH(1–34)NH_2; [^{Cha11}, Aib^{16}]hPTH(1–34)$_2$; [^{Cha7}, Aib^{34}]hPTH(1–34) NH_2; [Cha^{11}, Aib^{34}]hPTH(1–34)NH_2; [Cha^{27}, Aib^{16}]hPTH(1–34)NH_2; [Cha^{27}, Aib^{34}]hPTH(1–34)NH_2; [Cha^{28}, Aib^{16}]hPTH(1–34)NH_2; [Cha^{28}, Aib^{34}]hPTH(1–34)NH_2; [Nle^{31}]hPTH(1–34)NH_2; [$hArg^{27}$]hPTH(1–34)NH_2; [Dap^1, $Nle^{8,18}$, Tyr^{34}]hPTH(1–34)NH_2; [Nle^{31}]bPTH(1–34)NH_2; [Nle^{31}]rPTH(1–34)NH_2; [$hArg^{27}$]bPTH(1–34)NH_2; [$hArg^{27}$]rPTH(1–34)NH_2; [$Cha^{7,11}$, Aib^{19}, Lys^{30}]hPTH(1–34)NH_2; [Aib^{12}]hPTH(1–34)NH_2; [$Cha^{24,28,31}$, Lys^{30}]hPTH(1–34)NH_2; [$Cha^{28,31}$]hPTH(1–34)NH_2; [$Cha^{7,11}$, $Nle^{8,18}$, Aib^{34}]hPTH(1–34)NH_2; [Aib^3]hPTH(1–34)NH_2; [Cha^8]hPTH(1–34)NH_2; [Cha^{15}]hPTH(1–34)NH_2; [$Cha^{7,11}$, Aib^{19}]hPTH(1–34)NH_2; [$Cha^{7,11}$, Aib^{16}]hPTH(1–34)NH_2; [Aib^{17}]hPTH(1–34)NH_2; [Cha^5]hPTH(1–34)NH_2; [$Cha^{7,11,15}$]hPTH(1–34)NH_2; [$Cha^{7,11}$, $Nle^{8,18}$, Aib^{19}, Tyr^{34}]hPTH(1–34)NH_2; and [$Cha^{7,11}$, $Nle^{8,18}$, Aib^{19}, Lys^{30}, Tyr^{34}]hPTH(1–34) NH_2.

In another aspect, this invention relates to peptides covered by the following formula:



wherein

A_1 is Ala or Dap;

A_3 is Ser or Aib;

A_5 is His or Cha;

A_7 is Leu, Cha, Nle, β-Nal, Trp, Pal, Phe, or p-X-Phe in which X is OH, a halogen, or CH_3;

A_8 is Leu or Cha;

A_{11} is Lys, Cha, Phe, or β-Nal;

A_{12} is Gly or Aib;

A_{15} is Ile, or Cha;

A_{16} is Gln or Aib;

A_{17} is Asp or Aib;

A_{18} is Leu, Aib, or Cha;

A_{19} is Arg or Aib;

A_{22} is Phe or Cha;

A_{23} is Phe or Cha;

A_{24} is Leu or Cha;

A_{27} is Leu or Cha;

A_{28} is Ile or Cha;

A_{30} is Glu or Lys;

A_{31} is Ile, Cha, or deleted;

A_{32} is His or deleted;

A_{33} is Thr or deleted;

A_{34} is Ala or deleted;

each of R_1 and R_2 is, independently, H, C_{1-12} alkanyl, C_{7-20} phenylalkyl, C_{11-20} naphthyalkyl, C_{1-12} hydroxyalkyl, C_{2-12} hydroxyalkenyl, C_{7-20} hydroxyphenylalkyl, or C_{11-20} hydroxynaphthylalkyl; or one and only one of R_1 and R_2 is COE_1 in which E_1 is C_{1-12} alkyl, C_{2-12} alkyl, C_{2-12} alkenyl, C_{7-20} phenylalkyl, C_{11-20} naphthylalkyl, C_{1-12} hydroxyalkyl, C_{2-12} hydroxyalkenyl, C_{7-20} hydroxyphenylalkyl, or C_{11-20} hydroxynaphthylalkyl; and

R_3 is OH, NH_2, C_{1-12} alkoxy, or NH—Y—CH_2—Z in which Y is a C_{1-12} hydrocarbon moiety and Z is H, OH, CO_2H or $CONH_2$;

provided that at least one of A_5, A_7, A_8, A_{11}, A_{15}, A_{18}, A_{22}, A_{23}, A_{24}, A_{27}, A_{28}, or A_{31} is Cha, or at least one of A_3, A_{12}, A_{16}, A_{17}, A_{18}, A_{19}, or A_{34} is Aib; or a pharmaceutically acceptable salt thereof. In one embodiment, at least one of A_7 and A_{11} is Cha. In another embodiment, at least one of A_{16} or A_{19} is Aib. Specific examples of peptides of the just-recited formula include, but are not limited to, [Cha^7]hPTHrP(1–34)NH_2; [Cha^{11}]hPTHrP(1–34)NH_2; [$Cha^{7,11}$]hPTHrP(1–34)NH_2; [Aib^{16}, Tyr^{34}]hPTHrP(1–34)NH_2; [Aib^{19}]hPTHrP(1–34)NH_2; [$Aib^{16,19}$]hPTHrP(1–34)NH_2; [$Cha^{7,11}$, Aib^{16}]hPTHrP(1–34)NH_2; and [$Cha^{7,11}$ Aib^{19}]hPTHrP(1–34)NH_2.

With the exception of the N-terminal amino acid, all abbreviations (e.g. Ala or A_1) of amino acids in this disclosure stand for the structure of —NH—CH(R)—CO—, wherein R is a side chain of an amino acid (e.g., CH_3 for Ala). For the N-terminal amino acid, the abbreviation stands for the structure of =N—CH(R)—CO—, wherein R is a side chain of an amino acid. β-Nal, Nle, Dap, Cha, Nva, Amp, Pal, and Aib are the abbreviations of the following α-amino acids: β-(2-naphthyl) alanine, norleucine, α,β-diaminopropionic acid, cyclohexylalanine, norvaline, 4-amino-phenylalanine, 3-pyridinylalanine, and α-aminoisobutyric acid, respectively.

In the above formula, hydroxyalkyl, hydroxyphenylalkyl, and hydroxynaphthylalkyl may contain 1–4 hydroxy substituents. Also, COE_1 stands for —C=O.E_1. Examples of —C=O.E_1 include, but are not limited to, acetyl and phenylpropionyl.

A peptide of this invention is also denoted herein by another format, e.g., [$Cha^{7,11}$]hPTH(1–34)NH_2, with the substituted amino acids from the natural sequence placed between the second set of brackets (e.g., Cha^7 for Leu^7, and Cha^{11} for Leu^{11} in hPTH). The abbreviation hPTH stands for human PTH, hPTHrP for human PTHrP, rPTH for rat PTH, and bPTH for bovine PTH. The numbers between the parentheses refer to the number of amino acids present in the

peptide (e.g., hPTH(1–34) is amino acids 1 through 34 of the peptide sequence for human PTH). The sequences for hPTH (1–34), hPTHrP(1–34), bPTH(1–34), and rPTH(1–34) are listed in Nissenson, et al., Receptor, 3:193 (1993). The designation "NH_2" in PTH(1–34)NH_2 indicates that the C-terminus of the peptide is amidated. PTH(1–34), on the other hand, has a free acid C-terminus.

Each of the peptides of the invention is capable of stimulating the growth of bone in a subject (i.e., a mammal such as a human patient). Thus, it is useful in the treatment of osteoporosis and bone fractures when administered alone or concurrently with antiresorptive therapy, e.g., bisphosphonates and calcitonin.

The peptides of this invention can be provided in the form of pharmaceutically acceptable salts. Examples of such salts include, but are not limited to, those formed with organic acids (e.g., acetic, lactic, maleic, citric, malic, ascorbic, succinic, benzoic, methanesulfonic, toluenesulfonic, or pamoic acid), inorganic acids (e.g., hydrochloric acid, sulfuric acid, or phosphoric acid), and polymeric acids (e.g., tannic acid, carboxymethyl cellulose, polylactic, polyglycolic, or copolymers of polylactic-glycolic acids).

A therapeutically effective amount of a peptide of this invention and a pharmaceutically acceptable carrier substance (e.g., magnesium carbonate, lactose, or a phospholipid with which the therapeutic compound can form a micelle) together form a therapeutic composition (e.g., a pill, tablet, capsule, or liquid) for administration (e.g., orally, intravenously, transdermally, pulmonarily, vaginally, subcutaneously, nasally, iontophoretically, or by intratracheally) to a subject. The pill, tablet, or capsule that is to be administered orally can be coated with a substance for protecting the active composition from the gastric acid or intestinal enzymes in the stomach for a period of time sufficient to allow it to pass undigested into the small intestine. The therapeutic composition can also be in the form of a biodegradable or nonbiodegradable sustained release formulation for subcutaneous or intramuscular administration. See, e.g., U.S. Pat. Nos. 3,773,919 and 4,767,628 and PCT Application No. WO 94/15587. Continuous administration can also be achieved using an implantable or external pump (e.g., INFUSAID™ pump). The administration can also be conducted intermittently, e.g., single daily injection, or continuously at a low dose, e.g., sustained release formulation.

The dose of a peptide of the present invention for treating the above-mentioned diseases or disorders varies depending upon the manner of administration, the age and the body weight of the subject, and the condition of the subject to be treated, and ultimately will be decided by the attending physician or veterinarian.

Also contemplated within the scope of this invention is a peptide covered by the above generic formula for use in treating diseases or disorders associated with deficiency in bone growth or the like, e.g., osteoporosis or fractures.

Other features and advantages of the present invention will be apparent from the detailed description and from the claims.

DETAILED DESCRIPTION OF THE INVENTION

Based on the description herein, the present invention can be utilized to its fullest extent. The following specific examples are to be construed as merely illustrative, and not limitative of the remainder of the disclosure in any way whatsoever. Further, all publications cited herein are incorporated by reference.

Structure

PTH(1–34) has been reported to have two amphophilic alpha helical domains. See, e.g., Barden, et al., Biochem., 32:7126 (1992). The first α-helix is formed between amino acid residues 4 through 13, while the second α-helix is formed between amino acid residues 21 through 29. Some peptides of this invention contain the substitution of Cha for one or more residues within or near these two regions of PTH(1–34), e.g., Cha^7 and Cha^{11} within the first α-helix or Cha^{27} and Cha^{28} within the second α-helix.

Also covered by this invention are variants of PTH(1–34) with the substitution of Aib for a residue adjacent to the α-helixes, e.g., Aib^{16}, Aib^{19}, and Aib^{34}; $hArg^{27}$ and Nle^{31}, or the substitution of Dpa for the N-terminal residue.

Synthesis

The peptides of the invention can be prepared by standard solid phase synthesis. See, e.g., Stewart, J. M., et al., Solid Phase Synthesis (Pierce Chemical Co., 2d ed. 1984). The following is a description of how [Aib^{34}]hPTH(1–34)NH_2 was prepared. Other peptides of the invention can be prepared in an analogous manner by a person of ordinary skill in the art.

The peptide was synthesized on an Applied Biosystems (Foster City, Calif.) model 430A peptide synthesizer which was modified to do accelerated Boc-chemistry solid phase peptide synthesis. See Schnoize, et al., Int. J. Peptide Protein Res., 90:180 (1992). 4-Methylbenz-hydrylamine (MBHA) resin (Peninsula, Belmont, Calif.) with the substitution of 0.93 mmol/g was used. The Boc amino acids (Bachem, Calif., Torrance, Calif.; Nova Biochem., LaJolla, Calif.) were used with the following side chain protection: Boc-Arg(Tos)-OH, Boc-Asp(OcHxl)-OH, Boc-Asn(Xan)-OH, Boc-Glu(OcHxl)-OH, Boc-His(DNP)-OH, Boc-Asn-GH, Boc-Val-OH, Boc-Leu-OH, Boc-Ser-OH, Boc-Gly-OH, Boc-Met-OH, Boc-Gln-OH, Boc-Ile-OH, Boc-Lys(2ClZ)-OH, Boc-Ser(Bzl)-OH, and Boc-Trp(Fm)-OH. The synthesis was carried out on a 0.14 mmol scale. The Boc groups were removed by treatment with 100% TFA for 2×1 min. Boc amino acids (2.5 mmol) were pre-activated with HBTU (2.0 mmol) and DIEA (1.0 mL) in 4 mL of DMF and were coupled without prior neutralization of the peptide-resin TFA salt. Coupling times were 5 min except for the Boc-Aib-OH and the following residue, Boc-Asn(Xan)-OH, wherein the coupling times were 20 min.

At the end of the assembly of the peptide chain, the resin was treated with a solution of 20% mercaptoethanol/10% DIEA in DMF for 2×30 min. to remove the DNP group on the His side chain. The N-terminal Boc group was then removed by treatment with 100% TFA for 2×2 min. After neutralization of the peptide-resin with 10% DIEA in DMF (1×1 min.), the formyl group on the side chain of Trp was removed by treatment with a solution of 15% ethanolamine/15% water/70% DMF for 2×30 min. The partially-deprotected peptide-resin was washed with DMF and DCM and dried under reduced pressure. The final cleavage was done by stirring the peptide-resin in 10 mL of HF containing 1 mL of anisole at 0° C. for 75 min. HF was removed by a flow of nitrogen. The residue was washed with ether (6×10 mL) and extracted with 4N HOAc (6×10 mL).

The peptide mixture in the aqueous extract was purified on a reversed-phase preparative high pressure liquid chromatography (HPLC) using a reversed phase VYDAC C_{18} column (Nest Group, Southborough, Mass.). The column was eluted with a linear gradient (10% to 45% of solution B over 130 min.) at a flow rate of 10 mL/min (Solution A=0.1% aqueous TFA; Solution B=acetonitile containing

0.1% of TFA). Fractions were collected and checked on analytical HPLC. Those containing pure product were combined and lyophilized to dryness. 62.3 mg of a white solid was obtained. Purity was >99% based on analytical HPLC analysis. Electro-spray mass spectrometer analysis gave the molecular weight at 4054.7 (in agreement with the calculated molecular weight of 4054.7).

The synthesis and purification of [$Cha^{7,11}$]hPTH (1–34) NH_2 was carried out in the same manner as the above synthesis of [Aib^{34}]hPTH(1–34)NH_2. The protected amino acid Boc-Cha-OH was purchased from Bachem, Calif. The purity of the final product was >98%, and the electron-spray mass spectrometer gave the molecular weight at 4197.0 (calculated molecular weight is 4196.9).

The full names for the abbreviations used above are as follows: Boc for t-butyloxycarbonyl, HF for hydrogen fluoride, Fm for formyl, Xan for xanthyl, Bzl for benzyl, Tos for tosyl, DNP for 2,4-dinitrophenyl, DMF for dimethylformamide, DCM for dichloromethane, HBTU for 2-(1H-Benzotriazol-1-yl)-1,1,3,3-tetramethyl uronium hexafluorophosphate, DIEA for diisopropylethylamine, HOAc for acetic acid, TFA for trifluoroacetic acid, 2ClZ for 2-chlorobenzyloxycarbonyl and OcHxl for O-cyclohexyl.

The substituents R_1 and R_2 of the above generic formula may be attached to the free amine of the N-terminal amino acid by standard methods known in the art. For example, alkyl groups, e.g., C_{1-12} alkyl, may be attached using reductive alkylation. Hydroxyalkyl groups, e.g., C_{1-12} hydroxyalkyl, may also be attached using reductive alkylation wherein the free hydroxy group is protected with a t-butyl ester. Acyl groups, e.g., COE_1, may be attached by coupling the free acid, e.g., E_1COOH, to the free amine of the N-terminal amino acid by mixing the completed resin with 3 molar equivalents of both the free acid and diisopropylcarbodiimide in methylene chloride for one hour and cycling the resulting resin through steps (a) to (f) in the above wash program. If the free acid contains a free hydroxy group, e.g., p-hydroxyphenylpropionic acid, then the coupling should be performed with an additional 3 molar equivalents of HOBT.

Other peptides of this invention can be prepared in an analogous manner by a person of ordinary skill in the art.

Functional Assays

A. Binding to PTH Receptor

The peptides of the invention were tested for their ability to bind to the PTH receptor present on SaOS-2 (human osteosarcoma cells). SaOS-2 cells (American Type Culture Collection, Rockville, Md.; ATCC #HTB 85) were maintained in RPMI 1640 medium (Sigma, St. Louis, Mo.) supplemented with 10% fetal bovine serum (FBS) and 2 mM glutamine at 37° C. in a humidified atmosphere of 5% CO_2 in air. The medium was changed every three or four days, and the cells were subcultured every week by trypsinization.

SaOS-2 cells were maintained for four days until they had reached confluence. The medium was replaced with 5% FBS in RPMI 1640 medium and incubated for 2 hrs at room temperature with 10×10^4 cpm mono-^{125}I-[$Nle^{8,18}$, Tyr^{34}(3-^{125}I)] bPTH(1–34)NH_2 in the presence of a competing peptides of the invention at various concentrations between 10^{-11}M to 10^{-4}M. The cells were washed four times with ice-cold PBS and lysed with 0.1M NaOH, and the radioactivity associated with the cells was counted in a scintillation counter. Synthesis of mono-^{125}I-[$Nle^{8,18}$, Tyr^{34}(3-^{125}I)] bPTH(1–34)NH_2 was carried out as described in Goldman, M. E., et al., Endocrinol., 123:1468 (1988).

The binding assay was conducted with various peptides of the invention, and the IC_{50} value, (half maximal inhibition of binding of mono-^{125}I-[$Nle^{8,18}$, Tyr^{34}(3-^{125}I)]bPTH(1–34)NH_2, for each peptide was calculated.

As shown in Table I, all of the tested peptides had a high binding affinity for the PTH receptor on the SaOS-2 cell.

B. Stimulation of Adenylate Cyclase Activity

The ability of the peptides of the invention to induce a biological response in SaOS-2 cells were measured. More specifically, any stimulation of the adenylate cyclase was determined by measuring the level of synthesis of cAMP (adenosine 3',5'-monophosphate) as described previously in Rodan, et al., J. Clin. Invest. 72:1511 (1983) and Goldman, et al., Endocrinol., 123:1468 (1988). Confluent SaOS-2 cells in 24 wells plates were incubated with 0.5 μCi [^{3}H] adenine (26.9 Ci/mmol, New England Nuclear, Boston, Mass.) in fresh medium at 37° C. for 2 hrs, and washed twice with Hank's balanced salt solution (Gibco, Gaithersburg, Md.). The cells were treated with 1 mM IBMX [isobutylmethylxanthine, Sigma, St. Louis, Mo.] in fresh medium for 15 min, and the peptides of the invention were added to the medium to incubate for 5 min. The reaction was stopped by the addition of 1.2M trichloroacetic acid (TCA) (Sigma, St. Louis, Mo.) followed by sample neutralization with 4N KOH. cAMP was isolated by the two-column chromatographic method (Salmon, et al., 1974, Anal. Biochem. 58, 541). The radioactivity was counted in a scintillation counter (Liquid Scintillation Counter 2200CA, PACKARD, Downers Grove, Ill.).

The respective EC_{50} values (half maximal stimulation of adenylate cyclase) for the tested peptides were calculated and shown in Table I. A_{11} tested peptides were found to be potent stimulators of adenylate cyclase activity, which is a biochemical pathway indicative as a proximal signal for osteoblast proliferation (e.g., bone growth).

TABLE I

PEPTIDE	Kd (μM)	EC_{50} (nM)
[$Cha^{7,11}$]hPTH(1–34)NH_2	0.01	0.6
[Cha^{23}]hPTH(1–34)NH_2	0.2	20
[Cha^{24}]hPTH(1–34)NH_2	0.1	10
[$Nle^{8,18}$, Cha^{27}]hPTH(1–34)NH_2;	0.05	2
[Cha^{28}]hPTH(1–34)NH_2	0.05	2.5
[Cha^{31}]hPTH(1–34)NH_2	0.03	4
[Aib^{16}]hPTH(1–34)NH_2;	0.004	0.7
[Aib^{19}]hPTH(1–34)NH_2;	0.005	0.6
[Aib^{34}]hPTH(1–34)NH_2;	0.007	3
[Nle^{31}]hPTH(1–34)NH_2;	0.004	0.7
[$hArg^{27}$]hPTH(1–34)NH_2	0.007	1
[Dap, $Nle^{8,18}$, Tyr^{34}]hPTH(1–34)NH_2	0.150	10
[$Cha^{24,28,31}$, Lys^{30}]hPTH(1–34)NH_2;	0.5	7
[$Cha^{7,11}$, $Nle^{8,18}$, Tyr^{34}]hPTH(1–34)NH_2	0.006	0.6
[$Cha^{7,11}$, $Nle^{8,18}$, $Aib^{16,19}$, Tyr^{34}]hPTH(1–34)NH_2	0.005	1.5
[$Cha^{7,11}$, $Nle^{8,18,31}$, $Aib^{16,19}$, Tyr^{34}]hPTH(1–34)NH_2	0.04	4
[Cha^{12}]hPTH(1–34)NH_2	0.005	2
[$Cha^{28,31}$]hPTH(1–34)NH_2	0.06	7
[$Cha^{7,11}$, $Nle^{8,18}$, Aib^{34}]hPTH(1–34)NH_2	0.03	1.5
[Cha^{15}]hPTH(1–34)NH_2	0.005	1.3
[$Cha^{7,11}$, Aib^{19}]hPTH(1–34)NH_2	0.007	0.5
[$Cha^{7,11}$, Aib^{16}]hPTH(1–34)NH_2	0.004	1.1
[$Aib^{16,19}$]hPTH(1–34)NH_2	0.004	0.6
[Aib^{12}]hPTH(1–34)NH_2	0.005	2
[Aib^3]hPTH(1–34)NH_2	0.004	1.1
[$Cha^{7,11}$, Aib^{19}, Lys^{30}]hPTH(1–34)NH_2	0.004	2
[Cha^7]hPTH(1–34)NH_2	0.02	2.3
[$Cha^{24,28,31}$]hPTH(1–34)NH_2	1.0	30

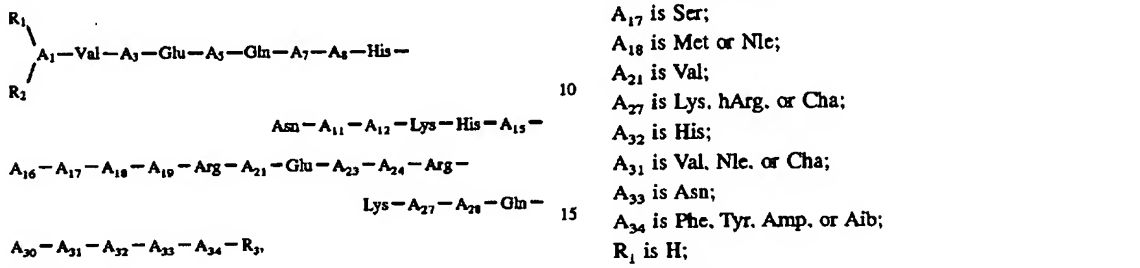
Other Embodiments

It is to be understood that while the invention has been described in conjunction with the detailed description thereof, that the foregoing description is intended to illus-

trate and not limit the scope of the invention, which is defined by the scope of the appended claims. Other aspects, advantages, and modifications are within the claims.

What is claimed:

1. A peptide of the formula:



wherein

A_1 is Ser, Ala, or Dap;

A_3 is Ser, Thr, or Aib;

A_5 is Ile or Cha;

A_7 is Leu, Nle, Cha, β-Nal, Trp, Pal, Phe, or p-X-Phe in which X is OH, a halogen, or CH_3;

A_8 is Met, Nva, Leu, Val, Ile, Cha, or Nle;

A_{11} is Leu, Nle, Cha, β-Nal, Trp, or Phe;

A_{12} is Gly;

A_{15} is Leu or Cha;

A_{16} is Ser, Asn, Ala, or Aib;

A_{17} is Ser, Thr, or Aib;

A_{18} is Met, Nva, Leu, Val, Ile, Nle, Cha, or Aib;

A_{19} is Glu or Aib;

A_{21} is Val, Cha, or Met;

A_{23} is Trp or Cha;

A_{24} is Leu or Cha;

A_{27} is Lys, Aib, Leu, hArg, Gln, or Cha;

A_{28} is Leu or Cha;

A_{30} is Asp or Lys;

A_{31} is Val, Nle, Cha, or deleted;

A_{32} is His or deleted;

A_{33} is Asn or deleted;

A_{34} is Phe, Tyr, Amp, Aib, or deleted;

each of R_1 and R_2 is, independently, H, C_{1-12} alkyl, C_{2-12} alkenyl, C_{7-20} phenylalkyl, C_{11-20} naphthylalkyl, C_{1-12} hydroxyalkyl, C_{2-12} hydroxyalkenyl, C_{7-20} hydroxyphenylalkyl, or C_{11-20} hydroxynaphthylalkyl; or one and only one of R_1 and R_2 is COE_1 in which E_1 is C_{1-12} alkyl, C_{2-12} alkenyl, C_{7-20} phenylalkyl, C_{11-20} naphthylalkyl, C_{1-12} hydroxyalkyl, C_{2-12} hydroxyalkenyl, C_{7-20} hydroxy-phenylalkyl, or C_{11-20} hydroxynaphthylalkyl; and

R_3 is OH, NH_2, C_{1-12} alkoxy, or NH—Y—CH_2—Z in which Y is a C_{1-12} hydrocarbon moiety and Z is H, OH, CO_2H, or $CONH_2$;

provided that at least one of A_5, A_7, A_{11}, A_{15}, A_{18}, A_{21}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha, or at least one of A_3, A_{16}, A_{17}, A_{18}, A_{19}, and A_{34} is Aib; or a pharmaceutically acceptable salt thereof.

2. A peptide of claim 1, wherein at least one of A_7, A_{11}, A_{15}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha; or a pharmaceutically acceptable salt thereof.

3. A peptide of claim 2, wherein

A_3 is Ser;

A_5 is Ile;

A_7 is Leu or Cha;

A_8 is Met, Nva, Leu, Val, Ile, or Nle;

A_{11} is Leu or Cha;

A_{12} is Gly;

A_{16} is Asn or Aib;

A_{17} is Ser;

A_{18} is Met or Nle;

A_{21} is Val;

A_{27} is Lys, hArg, or Cha;

A_{32} is His;

A_{31} is Val, Nle, or Cha;

A_{33} is Asn;

A_{34} is Phe, Tyr, Amp, or Aib;

R_1 is H;

R_2 is H; and

R_3 is NH_2;

or a pharmaceutically acceptable salt thereof.

4. A peptide of claim 3, wherein at least one of A_7 and A_{11} is Cha; or a pharmaceutically acceptable salt thereof.

5. A peptide of claim 4, wherein said peptide is [$Cha^{7, 11}$]hPTH(1–34)NH_2, [$Cha^{7, 11}$, $Nle^{8, 18}$, Tyr^{34}]hPTH (1–34)NH_2; [Cha^{11}]hPTH(1–34)NH_2; or [Cha^{7}]hPTH (1–34)NH_2; or a pharmaceutically acceptable salt thereof.

6. A peptide of claim 3, wherein at least one of A_{15}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha; or a pharmaceutically acceptable salt thereof.

7. A peptide of claim 6, wherein said peptide is [Cha^{23}] hPTH(1–34)NH_2, [Cha^{24}]hPTH(1–34)NH_2, [$Nle^{8, 18}$, Cha^{27}]hPTH (1–34)NH_2, [Cha^{28}]hPTH(1–34)NH_2, [Cha^{31}] hPTH(1–34) NH_2, [$Cha^{24, 28, 31}$]hPTH(1–34)NH_2; [$Cha^{24, 28, 31}$, Lys^{30}]hPTH(1–34)NH_2; [$Cha^{28, 31}$]hPTH (1–34)NH_2; or [Cha^{15}]hPTH(1–34)NH_2; or a pharmaceutically acceptable salt thereof.

8. A peptide of claim 1, wherein at least one of A_3, A_{16}, A_{17}, A_{18}, A_{19}, and A_{34} is Aib; or a pharmaceutically acceptable salt thereof.

9. A peptide of claim 8, wherein

A_3 is Ser or Aib;

A_5 is Ile;

A_7 is Leu or Cha;

A_8 is Met, Nva, Leu, Val, Ile, or Nle;

A_{11} is Leu or Cha;

A_{16} is Asn or Aib;

A_{18} is Met, Aib, or Nle;

A_{21} is Val;

A_{27} is Lys, Aib, Leu, hArg, or Cha;

A_{31} is Val, Nle, or Cha;

A_{32} is His;

A_{33} is Asn;

A_{34} is Phe, Tyr, Amp, or Aib;

R_1 is H;

R_2 is H; and

R_3 is NH_2;

or a pharmaceutically acceptable salt thereof.

10. A peptide of claim 9, wherein at least one of A_3, A_{16}, A_{19}, and A_{34} is Aib; or a pharmaceutically acceptable salt thereof.

11. A peptide of claim 10, wherein said peptide is [Aib^{16}] hPTH(1–34)NH_2, [Aib^{19}]hPTH(1–34)NH_2, [Aib^{34}]hPTH (1–34)NH_2; [$Aib^{16, 19}$]hPTH(1–34)NH_2; or [Aib^{3}]hPTH (1–34)NH_2; or a pharmaceutically acceptable salt thereof.

12. A peptide of claim 1 wherein at least one of A_7, A_{11}, A_{15}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha and at least one of A_3, A_{16}, A_{17}, A_{18}, A_{19}, and A_{34} is Aib; or a pharmaceutically acceptable salt thereof.

13. A peptide of claim 12, wherein

A_3 is Ser or Aib;

A_5 is Ile;

A_7 is Leu or Cha;

A_8 is Met, Nva, Leu, Val, Ile, or Nle;

A_{11} is Leu or Cha;

A_{16} is Asn or Aib;

A_{18} is Met, Aib, or Nle;

A_{21} is Val;

A_{27} is Lys, Aib, Leu, hArg, or Cha;

A_{31} is Val, Nle, or Cha;

A_{32} is His;

A_{33} is Asn;

A_{34} is Phe, Tyr, Amp, or Aib;

R_1 is H;

R_2 is H; and

R_3 is NH_2;

or a pharmaceutically acceptable salt thereof.

14. A peptide of claim 13, wherein at least one of A_7 and A_{11} is Cha and at least one of A_{16}, A_{19}, and A_{34} is Aib; or a pharmaceutically acceptable salt thereof.

15. A peptide of claim 14, wherein said peptide is [$Cha^{7,11}$, $Nle^{8,18}$, $Aib^{16,19}$, Tyr34]hPTH(1–34)NH_2, [$Cha^{7,11}$, $Nle^{8,18,31}$, $Aib^{16,19}$, Tyr^{34}]hPTH(1–34)NH_2; [$Cha^{7,11}$, Aib^{19}]hPTH(1–34)NH_2; [$Cha^{7,11}$, Aib^{16}]hPTH(1–34)NH_2; [$Cha^{7,11}$, $Nle^{8,18}$, Aib^{34}]hPTH(1–34)NH_2; or [$Cha^{7,11}$, Aib^{19}, Lys^{30}]hPTH(1–34)NH_2; or a pharmaceutically acceptable salt thereof.

16. A peptide of claim 13, wherein at least one of A_{24}, A_{28}, and A_{31} is Cha and at least one of A_{16} and A_{17} is Aib; or a pharmaceutically acceptable salt thereof.

17. A peptide of claim 16, wherein said peptide is [Cha^{28}, $Nle^{8,18}$, $Aib^{16,19}$, Tyr34]hPTH(1–34)NH_2, or [Cha^{28}, $Aib^{16,19}$]PTH(1–34)NH_2; or a pharmaceutically acceptable salt thereof.

18. A peptide of the formula:

$$R_1 \diagdown A_1\text{—Val—}A_3\text{—Glu—}A_5\text{—Gln—}A_7\text{—}A_8\text{—His—} \diagup R_2$$

$$\text{Asn—}A_{11}\text{—}A_{12}\text{—Lys—His—}A_{15}\text{—}A_{16}\text{—}A_{17}\text{—}A_{18}\text{—}A_{19}\text{—Arg—}A_{21}\text{—Glu—}A_{23}\text{—}A_{24}\text{—Arg—Lys—}A_{27}\text{—}A_{28}\text{—Gln—}A_{30}\text{—}A_{31}\text{—}A_{32}\text{—}A_{33}\text{—}A_{34}\text{—}R_3,$$

wherein

A_1 is Dap;

A_3 is Ser, Thr, or Aib;

A_5 is Ile or Cha;

A7 is Leu, Nle, Cha, β-Nal, Trp, Pal, Phe, or p-X-Phe in which X is H, OH, a halogen, or CH_3;

A_8 is Met, Nva, Leu, Val, Ile, Cha, or Nle;

A_{11} is Leu, Nle, Cha, β-Nal, Trp, or Phe;

A_{12} is Gly or Aib;

A_{15} is Leu or Cha;

A_{16} is Ser, Asn, Ala, or Aib;

A_{17} is Ser, Thr, or Aib;

A_{18} is Met, Nva, Leu, Val, Ile, Nle, Cha, or Aib;

A_{19} is Glu or Aib;

A_{21} is Val, Cha, or Met;

A_{23} is Trp or Cha;

A_{24} is Leu or Cha;

A_{27} is Lys, Aib, Leu, hArg, Gln, or Cha;

A_{28} is Leu or Cha;

A_{30} is Asp or Lys;

A_{31} is Val, Nle, Cha, or deleted;

A_{32} is His or deleted;

A_{33} is Asn or deleted;

A_{34} is Phe, Tyr, Amp, Aib, or deleted;

each of R_1 and R_2 is, independently, H, C_{1-12} alkyl, C_{2-12} alkenyl, C_{7-20} phenylalkyl, C_{11-20} naphthylalkyl, C_{1-12} hydroxyalkyl, C_{2-12} hydroxyalkenyl, C_{7-20} hydroxyphenylalkyl, or C_{11-20} hydroxynaphthylalkyl; or one and only one of R_1 and R_2 is COE_1 in which E_1 is C_{1-12} alkyl, C_{2-12} alkenyl, C_{7-20} phenylalkyl, C_{11-20} naphthylalkyl, C_{1-12} hydroxyalkyl, C_{2-12} hydroxyalkenyl, C_{7-20} hydroxy-phenylalkyl, or C_{11-20} hydroxynaphthylalkyl;

R_3 is OH, NH_2, C_{1-12} alkoxy, or NH—Y—CH_2—Z in which Y is a C_{1-12} hydrocarbon moiety and Z is H, OH, CO_2H, or $CONH_2$;

or a pharmaceutically acceptable salt thereof.

19. A peptide of claim 18, wherein

A_1 is Dap;

A_3 is Ser or Aib;

A_5 is Ile;

A_7 is Leu or Cha;

A_8 is Met, Nva, Leu, Val, Ile, or Nle;

A_{16} is Asn or Aib;

A_{18} is Met, Aib, or Nle;

A_{21} is Val;

A_{27} is Lys, Aib, Leu, hArg, or Cha;

A_{31} is Val, Nle, or Cha;

A_{32} is His;

A_{33} is Asn;

A_{34} is Phe, Tyr, Amp, or Aib;

R_1 is H;

R_2 is H; and

R_3 is NH_2;

or a pharmaceutically acceptable salt thereof.

20. A peptide of claim 19, wherein said peptide is [Dap^1, $Nle^{8,18}$, Tyr^{34}]hPTH(1–34)NH_2; or a pharmaceutically acceptable salt thereof.

21. A peptide of the formula:

$$R_1 \diagdown A_1\text{—Val—}A_3\text{—Glu—}A_5\text{—Gln—}A_7\text{—}A_8\text{—His—} \diagup R_2$$

$$\text{Asp—}A_{11}\text{—}A_{12}\text{—Lys—Ser—}A_{15}\text{—}A_{16}\text{—}A_{17}\text{—}A_{18}\text{—}A_{19}\text{—Arg—Arg—}A_{22}\text{—}A_{23}\text{—}A_{24}\text{—His—His—}A_{27}\text{—}A_{28}\text{—Ala—}A_{30}\text{—}A_{31}\text{—}A_{32}\text{—}A_{33}\text{—}A_{34}\text{—}R_3$$

wherein

A_1 is Ala or Dap;

A_3 is Ser or Aib;

A_5 is His or Cha;

A_7 is Leu, Cha, Nle, β-Nal, Trp, Pal, Phe, or p-X-Phe in which X is OH, a halogen, or CH_3;

A_8 is Leu or Cha;

A_{11} is Lys, Cha, Phe, or β-Nal;

A_{12} is Gly;

A_{15} is Ile, or Cha;

A_{16} is Gln or Aib;

A_{17} is Asp or Aib;

A_{18} is Leu, Aib, or Cha;

A_{19} is Arg or Aib;

A_{22} is Phe or Cha;

A_{23} is Phe or Cha;

A_{24} is Leu or Cha;

A_{27} is Leu or Cha;

A_{28} is Ile or Cha;

A_{30} is Glu or Lys;

A_{31} is Ile, Cha, or deleted;

A_{32} is His or deleted;

A_{33} is Thr or deleted;

A_{34} is Ala or deleted;

each of R_1 and R_2 is, independently, H, C_{1-12} alkyl, C_{7-20} phenylalkyl, C_{11-20} naphthylalkyl, C_{1-12} hydroxyalkyl, C_{2-12} hydroxyalkenyl, C_{7-20} hydroxyphenylalkyl, or C_{11-20} hydroxynaphthylalkyl; or one and only one of R_1 and R_2 is COE_1 in which E_1 is C_{1-12} alkyl, C_{2-12} alkenyl, C_{7-20} phenylalkyl, C_{11-20} naphthylalkyl, C_{1-12} hydroxyalkyl, C_{2-12} hydroxyalkenyl, C_{7-20} hydroxyphenylalkyl, or C_{11-20} hydroxynaphthylalkyl; and

R_3 is OH, NH_2, C_{1-12} alkoxy, or NH—Y—CH_2—Z in which Y is a C_{1-12} hydrocarbon moiety and Z is H, OH, CO_2H or $CONH_2$;

provided that at least one of A_5, A_7, A_{11}, A_{15}, A_{18}, A_{22}, A_{23}, A_{24}, A_{27}, A_{28}, and A_{31} is Cha, or at least one of A_3, A_{16}, A_{17}, A_{18}, A_{19}, and A_{34} is Aib; or a pharmaceutically acceptable salt thereof.

22. A peptide of claim 21, wherein at least one of A_7 and A_{11} is Cha; or a pharmaceutically acceptable salt thereof.

23. A peptide of claim 22, wherein at least one of A_{16} or A_{19} is Aib; or a pharmaceutically acceptable salt thereof.

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